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# THE CLIMATE IN PASTEL MICROCLIMATE CARDBOARD BOXES WHEN EXPOSED TO FLUCTUATING CLIMATES

**Keywords:** pastel, microclimate, relative humidity, temperature, fluctuation, infrared radiation

## ABSTRACT

Mock-up pastels were placed inside different framing systems and exposed to fluctuating relative humidity and temperature. Although the boxes were exposed to large spatial fluctuations, the relative humidity inside remained stable. From these experiments, it was decided to measure the air exchange rate of the most promising box. From the results, it was thought necessary to make the box more airtight using a laminated barrier foil. This airtight box was exposed to infrared heat to investigate the temperature and relative humidity changes within the box as a result of non-uniform heat exposure. It was found that different temperature zones within the package showed different relative humidity levels. The observed relative humidity gradients and changes are typically larger than the fluctuations found in the uniform heating exposure. The results were used to verify an existing moisture transport model.

## RÉSUMÉ

Des modèles de pastels ont été placés à l'intérieur de différents systèmes d'encadrement puis exposés à une température et une humidité relative fluctuantes. Bien que les boîtes aient été exposées à d'importantes variations spatiales, l'humidité relative est demeurée stable à l'intérieur. À partir de ces essais, il a été décidé de mesurer le taux de renouvellement de l'air de la boîte la plus prometteuse. Selon les résultats, il a été jugé nécessaire d'accroître l'étanchéité à l'air de la boîte à l'aide d'une feuille laminée faisant office de barrière. Cette boîte étanche à l'air a été exposée à la chaleur infrarouge afin d'étudier les variations de température et d'humidité relative à l'intérieur de la boîte suite à une exposition à une chaleur non uniforme. L'ex-

## INTRODUCTION

In 2013, the Rijksmuseum's collections will be presented to the public in the newly restored historic building in Amsterdam. The museum will show Dutch art and history in an international context from 1200 until today. In this new display, the collection of 18th-century pastels will play an important role. Nine pastels by Tischbein (1750–1812) and 21 pastels by Liotard (1702–1789) out of a collection of 262 pastels will be exhibited when the museum reopens.

Different techniques were used to produce these art works: besides pastel, there are examples of the use of gouache, white and black chalk and graphite. Most of the pastels are drawn on parchment; some are drawn on paper, mounted on a canvas or a wooden panel and one is directly drawn on canvas. The Parchment and canvasses are either glued or pinned to stretchers, some of which were replaced by pressed or plywood in the past. Some of the surfaces were fixed, while others were not. None of the pastels were still inside their original framing system. During the 20th century, zinc plates were sometimes combined with triplex or another type of pressed wood for backing boards. Most of the self-adhesive standard packing tapes (rubber-based adhesives on a plastic carrier) that were used during two major conservation campaigns performed in 1957 and 1977 have either loosened or become detached.

The pastels show different types of climate-related damage such as mold, stretcher effect and corner cracks. Most self-adhesive tapes used in the past to seal the frames against dust have deteriorated. This has allowed dust to enter the framings and caused visible discoloration that reduces the contrast of the pastel layer. Since none of the current framing system was originally designed by Liotard or Tischbein, the museum has decided to undertake a conservation and re-framing campaign.

The goal of this project was to develop a new mounting and framing method using only inert materials without any self-adhesives that would fit into the original wooden frames without any adjustments, similar to the work by Sozzani (1997). The second objective was to optimise climatic conditions inside the micro-environment around the pastel and to reduce the infiltration of dust. The research presented in this paper describes experiments that were performed to study the protective

périence a montré que différentes zones de température à l'intérieur de l'emballage présentaient différents niveaux d'humidité relative. Les gradients et les variations d'humidité relative observés sont de manière générale supérieurs aux fluctuations constatées lors de l'exposition à une chaleur uniforme. Ces résultats ont été utilisés pour vérifier un modèle existant de transport de l'humidité.

## RESUMEN

Se colocaron réplicas de pasteles dentro de diferentes sistemas de enmarcado y se expusieron a condiciones fluctuantes de temperatura y humedad relativa. Aunque las cajas se expusieron a fluctuaciones en espacios amplios, la humedad relativa en su interior se mantuvo estable. A partir de estos experimentos, se decidió medir la tasa de intercambio de aire de la caja más prometedora. A partir de los resultados, se pensó que era necesario hacer que la caja fuera más hermética utilizando una hoja laminada como barrera. Esta caja hermética se expuso a calor infrarrojo para investigar los cambios de temperatura y humedad relativa de su interior como resultado de la exposición a un calor no uniforme. Se descubrió que las zonas con diferentes temperaturas dentro del embalaje mostraban diferentes niveles de humedad relativa. Los gradientes de humedad relativa y los cambios observados son típicamente mayores que las fluctuaciones encontradas con una exposición uniforme al calor. Los resultados se utilizaron para verificar un modelo existente de transporte de humedad.

qualities of this new cardboard box when exposed to large climate fluctuations.

## EXPERIMENTAL

Mock-up pastels on parchment were prepared and placed inside 2 boxes, one with a microclimate drawer box (MCDB) and one without. A schematic representation of the drawer package is given in Figure1. As a reference, one pastel was placed inside a frame with glass and a backboard (the results are not presented in this paper), imitating the 18th-century description by Chaperon in his treatise on pastel paintings.[1]

In the first experiment, relative humidity (RH) and temperature near the pastel was monitored while the boxes were exposed to a fluctuating RH at constant temperature. RH was reduced from 75% to 20% as fast as possible and maintained at 20% for 4 hours. It was then increased back up to 75% for a further 4 hours. This cycle was repeated 20 times.

To determine the exchange of air between box and room, the air exchange rate of the microclimate box was determined in experiment 2. After this measurement, it was decided to reduce the leakage rate by applying Hermann Nawrot AG® (polyethylene aluminium laminate) on the outside of the box. A schematic representation of the MCDB without the moisture barrier is given in Figure 1, including the location of the sensors.

In the third experiment, only the MCDB was investigated for the effect of temperature fluctuations with increasing amplitude at constant RH (Figure 1 and Table 1).

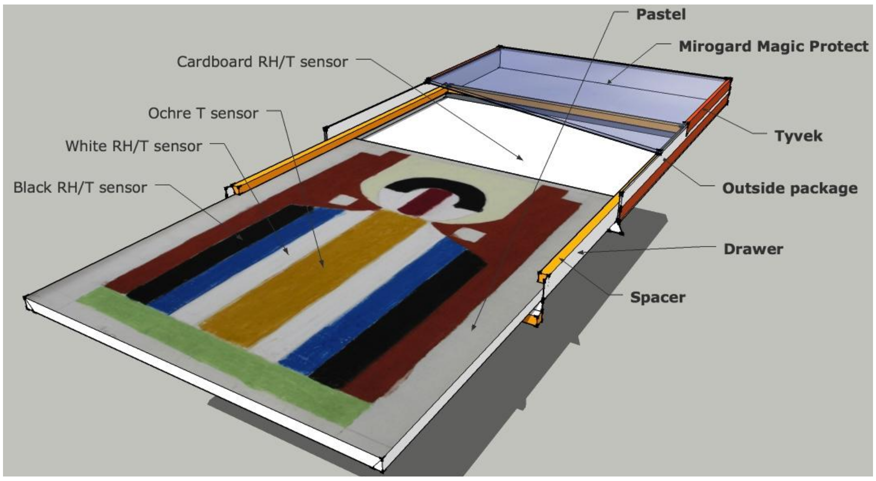



**Figure 1**
Schematic presentation of the pastel drawer cardboard box, indicating the location of the surface temperature sensors on the back of the parchment

For the fourth experiment, the box was placed on a temperature controlled wall that was climatised at 15°C and 20°C. To monitor surface temperatures of the pastel with a FLIR Thermocam Infrared camera, the glass was temporary replaced by a thin layer of polyethylene sheet. The polyethylene was applied in such a way that leakage was reduced to a minimum. The occurrence of leaks was not tested and can therefore not be excluded. An infrared heater was placed at a distance of 2 meters at an angle of less than 45 degrees to the surface of the microclimate box and the infrared camera. RH/T sensors were placed on the back of the parchment and inside the drawer (see Figure 1) and one at the rear of the box (not presented in Figure 1).

## RESULTS

### Experiment 1: fluctuating RH

The microclimate boxes were exposed to large and fast fluctuations of relative humidity (20–75%). The amplitude of this relative humidity fluctuation far exceeds what is expected to occur in regular museum storage or exhibition rooms and should be considered a worst case scenario.

The RH and temperature data collected inside the box showed, as expected (Thickett 2005), that even though the relative humidity in the room fluctuates rapidly and enormously, the microclimate in the box is stable at around 55%, which was the RH in the room when the MCDB was closed.

### Experiment 2: air exchange rate

The air exchange rate of both the MCDB was determined with and without a Hermann Nawrot AG® vapour barrier. The box was flushed with $CO_2$ until the $CO_2$ concentration was around 10,000 ppm. The climate box was placed inside the climate chamber at a constant temperature of 20°C and the decreasing $CO_2$ concentration was measured continuously.

The air exchange rate was initially 0.48 hour $^{-1}$ and 0.048 day $^{-1}$ after application of the vapour barrier. The Hermann Nawrot AG® reduces the air exchange by a factor of 10.

### Fluctuating temperature

Two types of temperature changes were induced within the box: by the all-air system of the climate chamber blowing heated air into the climate chamber (uniformly) and by an infrared radiation source (direct, local heating).

### Experiment 3: uniform temperature changes

A detail of the full exposure to uniform temperature fluctuations can be seen in Figure 2, where it can be observed that a uniform temperature increase/decrease in the room leads to a temperature increase/decrease inside the box. This temperature fluctuation causes a change in relative humidity. A temperature increase leads to an increase in the relative humidity. When the amplitude of the fluctuation increases, the relative humidity fluctuation increases (Figure 2).

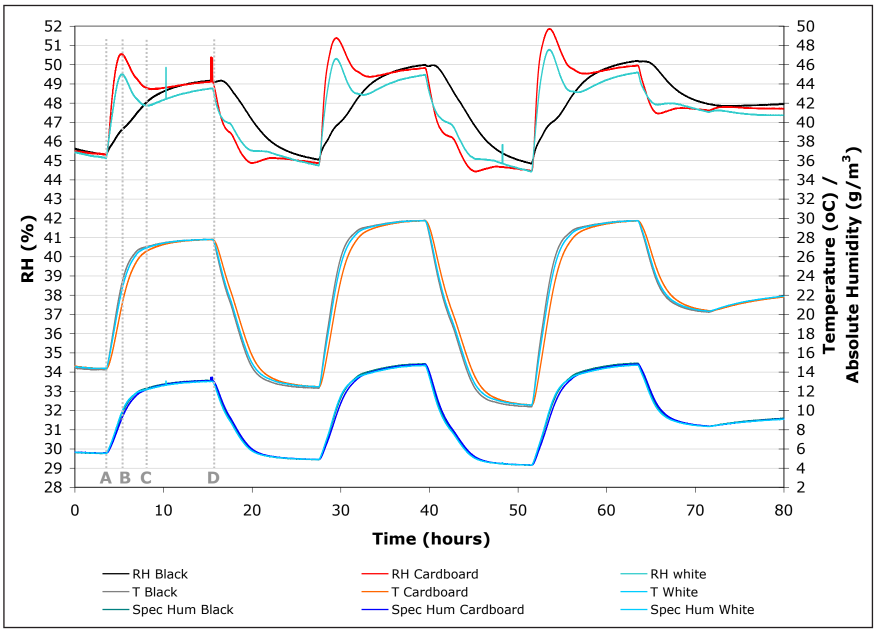



**Figure 2**

Relative humidity, temperature and absolute humidity profiles inside the MCDB when exposed to increasing temperature fluctuations

At point A, the HVAC controlling the climate inside the climate chamber starts to change the temperature from 14°C to 28°C. Inside the MCDB, the temperature profile (lines in the middle of the graph) shows a linear increase, after which the increase is tempered (after point B). The absolute humidity (blue lines at the bottom of the graph) shows a similar increase that can be related to the release of moisture by the hygroscopic materials inside the package: parchment, wood and cardboard. An increase in the temperature fluctuation gives an increase in the absolute humidity fluctuation. All temperature zones show very similar specific humidities, but slightly different relative humidities. The relative humidity profiles are more varied: for the cardboard and white sensors, first an increase (A→B) then a rapid decrease (B→C) and finally a subtle increase (C→D) can be observed. At first, the RH increases due to the moisture released by the cardboard and parchment – the sensor closest to the cardboard shows the highest RH increase (red line). RH at the parchment surface, behind the black surface, shows the slowest change in RH, without this initial maximum. It is unclear why the parchment behind the black surface reacts differently locally than the white and cardboard surfaces.

Within the closed system, equilibrium is reached after approximately 11 hours, without a significant RH difference between the sensors located behind the white and the black surface (which is similar to the RH near the cardboard). A maximum is reached after which the cardboard buffers the internal RH to 49% at 28°C. The other equilibriums are presented in Table 2, showing a maximum RH change of approximately 5%, from 10°C to 30°C.

In this experiment, roughly 10 cycles were studied. Even though an increase in the internal relative humidity as a result of temperature fluctuations can be expected (Knop et al. 2007), this was not observed in our experiments. For long exposure times, such as a permanent exhibition, large temperature fluctuations could be a risk. Care should also be taken to ensure the released moisture does not leave the package.

## Experiment 4: local non-uniform temperature changes

The experiments performed at different wall temperatures (15 and 20°C) showed very similar behaviour, one of which is discussed in further detail below.

Temperature and relative humidity profiles inside the package are shown in Figure 3. It can be clearly seen that the surface temperatures on the pastel depend on the colour applied to the front: the black absorbs most heat. After about half an hour of exposure to a strong infrared light source, the black surface (black dotted line) reaches a maximum temperature of 43°C, while the more reflective white surface (red dotted line) reaches 36°C. The air inside the box (blue dotted line) heats up to 32°C.

Again, the absolute humidity inside the box increases from 7.7 to about 21 g/m$^3$ as the temperature rises. This can be explained by the moisture released by the largest hygroscopic mass within the package, i.e. the cardboard, due to heating (Ligterink et al. 2007). Not all temperature zones, i.e. black, white and inside the cardboard, reach the same uniform level of absolute humidity. After switching off the infrared light source, the system does not reach its moisture or temperature equilibrium immediately. Based on the extrapolation of the temperature curves in Figure 3, this temperature equilibrium is usually reached after approximately 75 minutes.

Relative humidity levels show three different profiles: an RH decrease near the black surface, a more or less stable profile behind the white surface and RH increase inside the cardboard drawer (see lines at the top in Figure 3).

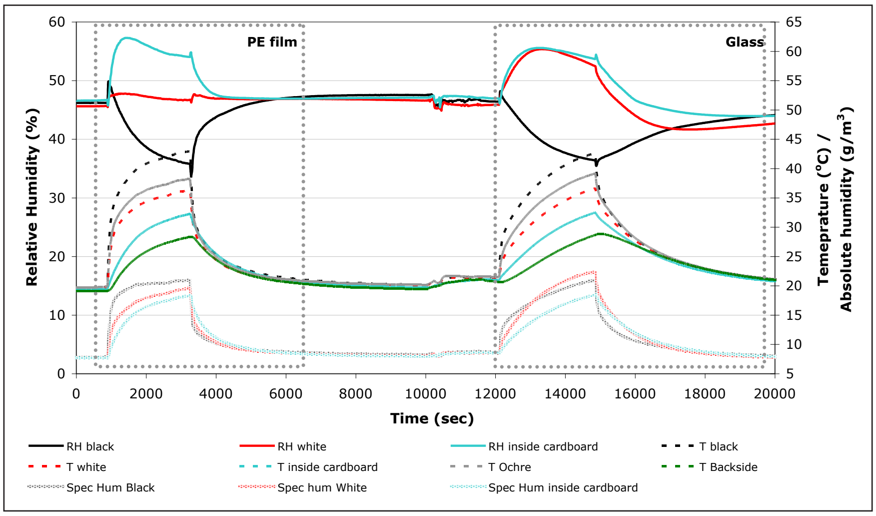



**Figure 3**
Relative humidity, temperature and absolute humidity profiles inside the MCDB with polyethylene film and glass covering placed on a wall at 20°C exposed to non-uniform heating by an infrared source

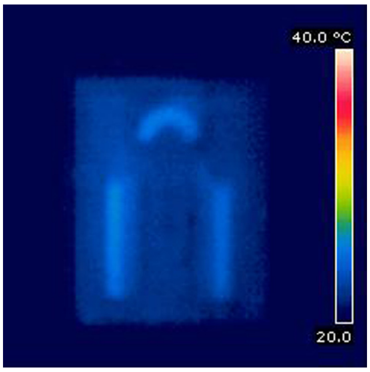



**Figure 4**
The surface temperatures of the pastel (using ε= 0.94; oil paint) upon heating with an infrared lamp after 15 seconds

During the experiment, the surface temperature was recorded using an infrared camera (see Figure 4). In these pictures, it can be seen that the black surface reaches the highest temperature.

The polyethylene layer was removed and replaced by the Microguard® glass. Again, the MCDB was exposed to the infrared light source for approximately 30 minutes. The climate data are presented in Figure 3.

The measured local relative humidities could have been estimated roughly using the model presented by Ligterink and Di Pietro (see equation 1), in which different temperature zones and hygroscopic masses are defined within the closed volume (Ligterink et al. 2007). Within the MCDB, most moisture is found inside the hygroscopic materials and not in the air. If, for example, some of the moisture in these materials is desorbed due a temperature increase, the absolute humidity in the air will increase and therefore the local RH will change drastically.

$$RH_x = \left[ \frac{\sum_j \left( \alpha RH^i + \beta \Delta T_j \right) M_j}{\sum_j \left( \alpha \frac{1}{c_{sat}\left(T_j\right)} \right) M_j} \right] \cdot \left( \frac{1}{c_{sat}\left(T_x\right)} \right) \qquad \text{(eq 1)}$$

In which:

$RH_x$ = the local relative humidity at section $x$ [0-1]

α = the dimensionless hygroscopicity factor [typically 0.15 for cellulose based materials]

β = the temperature coefficient [typically 0.0008°C$^{-1}$ for cellulose based materials]

$RH^i$ = initial relative humidity [0-1]

$\Delta T_j$ = the temperature shift for section $j$, defined as: $T_j - T_i$ (°C)

$M_j$ = the dry mass of section $j$ (g)

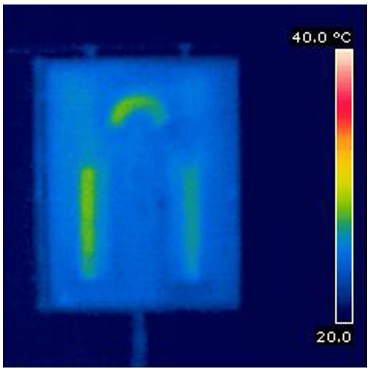
$c_{sat}\left(T_j\right)$ = the saturation absolute humidity at a given temperature (g/m$^3$)

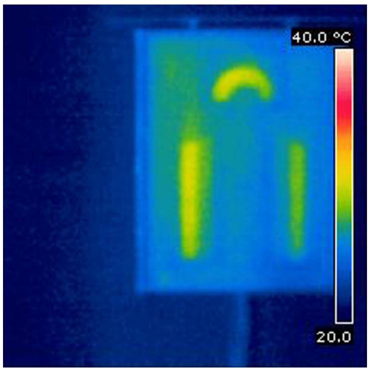
$c_{sat}\left(T_x\right)$ = the saturation absolute humidity at a given temperature at section $x$ (g/m$^3$)

This equation basically consists of two parts. The square brackets contain the sum of all absolute humidities at all temperature zones, which gives the overall absolute humidity of the closed system. The second part, between the round brackets, contains the calculation for the saturation absolute humidity (given in Table 1) at the temperature of a specific temperature zone.

Based on the temperature measurements during the IR experiment with the PE covering, it is assumed that the MCDB can be simplified into a system with only four different temperature zones: black, ochre, white and cardboard. To estimate the local relative humidity for a specific temperature zone, the dry mass and equilibrium temperature for each zone is specified (see Table 1).

Due to the relatively large amount of dry mass stemming from the cardboard, the absolute humidity in the system is predominantly determined by



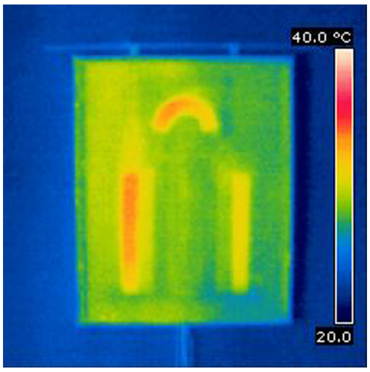




**Figure 5**
The surface temperatures of the pastel (using ε= 0.94; oil paint) upon heating with an infrared lamp after 3 minutes

**Figure 6**
The surface temperatures of the pastel (using ε= 0.94; oil paint) upon heating with an infrared lamp after 10 minutes

**Figure 7**
The surface temperatures of the pastel (using ε= 0.94; oil paint) upon heating with an infrared lamp after 35 minutes

this (actually the cardboard plus the surface of the wood) and reaches approximately 23.4 g/m$^3$. This value comes quite close to the expected value when the absolute humidity lines in Figure 3 are extrapolated to equilibrium (not presented in the figure).

**Table 1**

Equilibrium temperatures, temperature change, saturation temperature and the dry mass for the 4 temperature zones

| $T^i$ | $T_{eq}$ | $\Delta T$ | RH | | $RH^i$ | $C_{sat}$ g/m$^3$ | Calculated | Measured |
|---|---|---|---|---|---|---|---|---|
| | | | min | max | | | $AH_{eq}$ | |
| 20.4 | 22 | 1.6 | 46.8 | 47 | 0.469 | 19.3 | 9.2 | 9.1 |
| 22 | 18.2 | -3.8 | 47.1 | 47.4 | 0.473 | 15.5 | 7.0 | 7.1 |
| 18.2 | 23.9 | 5.7 | 46.1 | 46.4 | 0.463 | 21.5 | 10.6 | 10.2 |
| 14.5 | 27.8 | 13.3 | 45.5 | 45.5 | 0.455 | 26.7 | 14.0 | 13.0 |
| 27.8 | 12.7 | -15.1 | 48.6 | 49.1 | 0.489 | 11.1 | 4.5 | 5.0 |
| 12.7 | 29.8 | 17.1 | 45.3 | 45.4 | 0.454 | 29.8 | 16.2 | 14.7 |
| 29.8 | 10.7 | -19.1 | 49.3 | 49.9 | 0.496 | 9.8 | 3.9 | 4.4 |
| 10.7 | 29.6 | 18.9 | 44.6 | 44.7 | 0.447 | 29.5 | 16.1 | 14.7 |

For each temperature zone, the local relative humidity can now be calculated using equation 1 and the saturation absolute humidity presented in Table 1. The local RH near the black surface will decrease to 36%, the ochre will be stable at 46%, the white will increase to 54% and the cardboard box will increase to 60%. The measured values for these locations (Figure 3) are different from the expected values: $RH_{black}$= 36%, $RH_{white}$= 46% and $RH_{cardboard}$= 54%, but still show the right trend.

The data collected for experiment 3 were also verified using the model. Because the temperature change is more or less uniform within the package (see Figure 2), only one temperature zone is used. In Table 2, data for all temperature fluctuations are presented with the measured and calculated final absolute humidity. It was found that the model will show the trend for the new absolute humidity and derived $RH_{calc}$, but not exactly. Differences between the calculated and measured data are possibly due to the fact that temperatures are less uniform than expected and that the amount of dry mass in the zones are estimated.

**Table 2**

Measured and calculated temperatures, relative humidities and absolute humidities for the uniform temperature fluctuation experiment

| | $T^i$ (°C) | $T_{eq}$ (°C) | $\Delta T$ (°C) | $RH^i$ (-) | $C_{sat}$ (g/m$^3$) | $AH_{eq}$ (g/m$^3$) | | $RH_{eq}$ (-) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Calculated | Measured | Calculated | Measured* |
| 1 | 20.4 | 22 | **1.6** | 0.47 | 19.3 | 9.2 | 9.1 | 0.47 | 0.48 |
| 2 | 22 | 18.2 | **-3.8** | 0.47 | 15.5 | 7.0 | 7.1 | 0.45 | 0.45 |
| 3 | 18.2 | 23.9 | **5.7** | 0.46 | 21.5 | 10.6 | 10.2 | 0.49 | 0.49 |
| 4 | 14.5 | 27.8 | **13.3** | 0.46 | 26.7 | 14.0 | 13.0 | 0.52 | 0.49 |
| 5 | 27.8 | 12.7 | **-15.1** | 0.49 | 11.1 | 4.5 | 5.0 | 0.41 | 0.44 |
| 6 | 12.7 | 29.8 | **17.1** | 0.45 | 29.8 | 16.2 | 14.7 | 0.54 | 0.51 |
| 7 | 29.8 | 10.7 | **-19.1** | 0.50 | 9.8 | 3.9 | 4.4 | 0.40 | 0.43 |
| 8 | 10.7 | 29.6 | **18.9** | 0.45 | 29.5 | 16.1 | 14.7 | 0.55 | 0.51 |

*Values are derived form direct data by extrapolation (estimated deviation in the RH value is ±0.03), for example the profiles presented in Figure 2.

## CONCLUSION

Pastels are generally considered to be very sensitive to RH fluctuations as the loosely bound particles are known to detach easily from their support. As long as research has not established acceptable RH fluctuation ranges, great care is taken to keep fluctuations as small as possible. The Rijksmuseum Amsterdam wants to make its highly valued pastel collection optimally accessible to the public, yet at minimal risk. Although the overall climatic conditions in the new exhibition rooms will be class A to accommodate the open displaying of mixed collections, it was decided to give the pastels extra protection by displaying them in microclimate boxes. A new microclimate box was designed for this purpose which contains a drawer allowing for the introduction of extra hygroscopic material and for handling without touching the object. Additionally, the airtight design minimizes dust and gaseous infiltration and provides a first protective barrier against fire and water incidents.

Tests with this MCDB frame showed that extreme eternal RH fluctuations of ±30% are completely flattened out. External temperature fluctuations will cause RH fluctuations inside the frame. Uniform heating will cause an increase in RH while uniform cooling causes a decrease. Yet large fluctuations of ±20°C will only result in relatively small fluctuations of ±5% RH. This is in line with previous studies on the behaviour of microclimate frames (Thickett 2005). These fluctuations are considered to cause no risk of mechanical damage to most artifacts and paintings (ASHRAE 2007).

Non-uniform temperature changes are a different matter. Short exposure of the MCDB to an infrared radiation source caused rapid local heating inside the frame and consequently relatively large RH gradients. After 30 minutes exposure, the temperature difference between a black and a white area of the pastel had increased to 6°C with a corresponding RH gradient of 13%. The RH difference between the black area and the cardboard behind it was even larger. Depending on the amount of hygroscopic material within a microclimate system, similar RH gradients and subsequent moisture transport from warm to cold spots can be expected when framed objects are hung on cold walls or exposed to direct sunlight or high intensity incandescent spotlight. Padfield et al. (2002) has described the mechanism for these observations already and Ligterink and Di Pietro (2007) have developed a model to predict local RH and absolute humidity at different temperatures zones in closed air volumes. The measurements described in this study confirm both theories. These earlier publications in combination with the results of the current study provide insight into the behaviour of microclimate frames in general and indicate which precautions to take when choosing this option to reduce climate risks.

The extreme situations causing unacceptable fluctuations in the MCDB frames are not expected in the new exhibitions of the Rijksmuseum Amsterdam, but should be kept in mind when applying microclimate frames in less favorable conditions. To minimize risks of RH fluctuations to sensitive objects like pastels in microclimate frames, one should:

- reduce the transport of air into the box by making the box as airtight as possible
- keep the volume of the micro climate box as small as possible
- add hygroscopic material to the internal volume
- prevent (strong) temperature gradients caused by local heat and/or cold sources close to the pastel or microclimate box. For pastels in original framing exhibited in historic houses on cold/warm outer walls, spacers can be placed between the object and the outside wall or the object should be placed elsewhere.

## NOTES

1 See Chaperon (1788). Glass is inserted in the frame, wooden or cork spacers are attached to the rabbet to create a distance between the glass and the pastel and thus avoid rubbing. A paper seal glued in the rabbet on top of the spacers prevents dust and insects from penetrating into the frame. After putting the pastel in the frame, the back is secured with a cardboard or wooden back almost as big as the frame and a paper seal is again glued on the periphery of the board in order to attach it to the frame and prevent dust and insects from entering.

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## MATERIALS LIST

Calf parchment
Laminated hard cardboards (1730g/$m^2$); Klug
Tyvek®; Dupont
Mirogard® Magic Protect glass; Schott
Evacon-R®; Conservation by Design Limited